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HEAT TRANSFER MEASUREMENTS ON A CONE-CYLINDER-FLARE AT A MACH NUMBER OF 6.8

by

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HEAT TRANSFER MEASUREMENTS ON A CONE-CYLINDER-FLARE AT A MACH NUMBER OF 6.8

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SUMMARY

Heat transfer measurements have been made in the R.A.E. Hypersonic Wind Tunnel on a cone-cylinder-flare and high values of the heat transfer factor found where the flow reattached on the flare.

Suggestions are made to improve the accuracy of future measurements of heat transfer in this facility.

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1 INTRODUCTION

One solution of the problem of re-entry into the Earth's atmosphere of a ballistic missile is to use a low-drag body, the surface of which ablates and so absorbs the heat generated during re-entry. The so-called cone-cylinder flare is typical of the low-drag bodies considered for this purpose, and this note presents the results of some heat transfer measurements made in the R.A.E. 7" x 7" hypersonic wind-tunnel on one of these bodies.

Before the tests were finished, the project was cancelled. However, some important conclusions were reached concerning the technique of heat transfer measurements in this wind-tunnel, and this report on the experiments is mainly a record of these conclusions.

The hypersonic tunnel is an intermittent tunnel, with a running time of a few minutes[1] and was operating at a Mach number of 6.8 during these tests. The model (known as G.W.18) was a cone-cylinder flare, and is drawn in Fig.1. The original decision was to make measurements of both pressure and heat transfer, especially over the rear of the model. It was therefore necessary to mount the model in such a way that the flow about the base was unimpeded by a sting - the usual support for a model in a wind-tunnel.

2 THE MODEL AND ITS INSTRUMENTATION

The model is shown in detail in Fig.1. It contained nine surface thermocouples and seven surface pressure holes. It was not possible to make accurate pressure measurements with this model because of the long time lag when the pressure measuring instrument[1] was switched from one pressure hole to another. This was not entirely unexpected, since the instrument had been designed for use with larger pressure tubes than could be fed through the small aperture in the pedestal mount used to support this particular model. Even so, the time lag was longer than had been anticipated.

The thermocouples were of constantan, with the steel of the model used as a common return. These thermocouples were then calibrated in an oven over the range of temperatures encountered during tests. The outputs from the thermocouples were fed to nine speedomax potentiometer chart recorders, so that a record of e.m.f. - and hence temperature - as a function of time was available for each thermocouple.

The pedestal mount used for this model was designed so as to influence the flow round the base of the model as little as possible. A series of tests to determine the extent of the influence upon the base flow of this system of mounting the model are planned to take place soon.

3 RESULTS

The model was tested at incidences of 0°, 5°, and 10°. Schlieren photographs of the flow at each incidence are shown in Fig.2.

The temperatures at each thermocouple location are plotted as a function of time in Figs.3(a), 3(b) and 3(c) for the three incidences. From these curves the value of the heat transfer factor h can be calculated by using

$$h = \frac{\rho c d}{\Delta T} \left(\frac{dT}{dt}\right)_{t=t_0} \qquad (1)$$

taking

$$\Delta T = 0.9 T_0 - T . \qquad (2)$$

This procedure is known as the 'transient' or 'heat pulse' technique. It is desirable to pick a value for t_o such that the temperature of the body is uniform, so that heat conduction within the body can be ignored. The only time during a tunnel run that the temperature of a body is uniform is for a brief period just after the start of flow - unless the body is of such simple geometry that it heats up uniformly. Unfortunately, in the hypersonic tunnel at present, the heat capacity of the pipework between the heater and the stagnation chamber is sufficiently large for the stagnation temperature (measured just upstream of the throat) to take 10 seconds and move to approach an equilibrium value (see Fig.4). Thus, at the start of flow, T_o has a low value, leading to low values of ΔT and $\frac{dT}{dt}$. If t_o were taken as zero, the value of h calculated from equation (1) could be considerably in error arising from small absolute errors in the measurement of T and T_o. To reduce errors from this source to tolerable proportions, it is necessary to take t_o = 5 seconds (at the very least); since the body heats up during this time corrections have to be made to equation (1) to take into account conduction of heat within the body.

If we assume that the skin of the body is thin, so that there is no variation of temperature with distance from the surface, the correction Δh to be added to the right hand side of equation (1) is

$$\Delta h = \frac{\kappa d}{\Delta T}\left(\frac{1}{y}\frac{dy}{dx}\frac{dT}{dx} + \frac{d^2 T}{dx^2}\right). \qquad (3)$$

Corrected and uncorrected values of h for zero incidence are shown in Fig.5. It can be seen that the magnitude of the correction at one point on the flare is more than 30% of the corrected value. It is undesirable for corrections to be as large as this, because errors in their estimation are themselves important, and the accuracy must inevitably be low. In particular, for this model the largest term in equation (3) was the second derivative, and the values obtained for it could easily have errors of the order of 30%.

In order to avoid errors arising from measuring very low values of stagnation temperature without introducing additional errors due to heat conduction within models, it is desirable to evaluate the derivative in equation (1) at the instant flow starts in the tunnel; but the stagnation temperature must be made to rise very rapidly to its equilibrium value. Until the equipment that has been designed to raise the temperature of the pipework between the heater and the settling chamber has been installed, it will not be possible to make measurements in the hypersonic tunnel from which accurate values of the heat transfer factor can be calculated, unless the body is of such a simple shape (such as a cone) that it heats up uniformly.

4 DISCUSSION OF RESULTS

The schlieren photographs (Fig.2(a)) show that at zero incidence the flow detaches from the cone-cylinder junction or thereabouts and reattaches on the flare. It is not therefore surprising to see in Fig.5 that the value of h reaches its maximum on the flare - h was not measured on the nose, where it would be higher still. As the model incidence increases (Fig.2(b) and 2(c)), the flow no longer reattaches on the leeward side of the flare, which is then immersed in a separated bubble, and the value of h is much lower. On the windward surface the attachment point, and hence the position of maximum flare

heating, would move upstream. Since only the top surface of the model was instrumented, it would have been necessary to make measurements at negative incidences in order to find how h behaved on the windward surface; and this was not done in the time available. However, it is doubtful whether the magnitude of the peak heating rate, as distinct from its position, would vary much with incidence.

The corrected results do not take into account heat conduction round the model since the skin temperatures were measured along one generator only. This additional correction will be zero at zero incidence, but will increase as incidence increases. The difficulty of evaluating it for a complicated shape emphasises the objections to the use of a non-zero value of t_o.

5 CONCLUSIONS

This particular model is not of simple geometry. The flow over the conical nose expands over the junction with the cylinder, probably giving rise to a local bubble of separated flow. Then the flow separates again, reattaches on the flare, and before it has time to settle down it has to expand into the base region. It is, therefore, not possible to make a straightforward theoretical analysis of the flow field round the model, and to use the experimental results to confirm or modify the theory, as would be possible for a model of a more simple shape. As a consequence, no general conclusions can be drawn from these experiments.

An analysis of the results has shown, however, that until an improvement is made in the stagnation temperature response in the working section at the beginning of a run[2], accurate measurements by the present transient technique are not possible on any uninsulated body along which the temperature distribution is markedly non-linear. It would be possible, however, to avoid this limitation by establishing the flow in the tunnel before exposing the model to the air-stream. This could be achieved either by placing some shields round the model and removing them very quickly, or by making arrangements to project the model rapidly into the air stream.

LIST OF SYMBOLS

c	specific heat of model wall
d	thickness of model wall
h	heat transfer factor $= \dfrac{\dot{q}}{T_r - T}$
$\dot{q}$	heat flow into model surface per unit time per unit area
T	model surface temperature
T_o	stagnation temperature
T_r	recovery temperature, assumed $= 0.9\ T_o$
t	time from start of flow
t_o	a value of t
x	distance from model-nose measured along surface
y	perimeter of model
ρ	density of model wall
κ	thermal conductivity of model wall

LIST OF REFERENCES

No.	Author	Title, etc.
1	Crabtree, L.F. Crane, J.F.W.	The 7" x 7" hypersonic wind tunnel at RAE Farnborough. Part 1. RAE Tech. Note No. Aero 2716 Sept. 1960 ARC 22486.
2	Crane, J.F.W.	The 7" x 7" hypersonic wind tunnel at RAE Farnborough. Part 2. RAE Tech. Note No. Aero 2717 Sept. 1960 ARC 23435.

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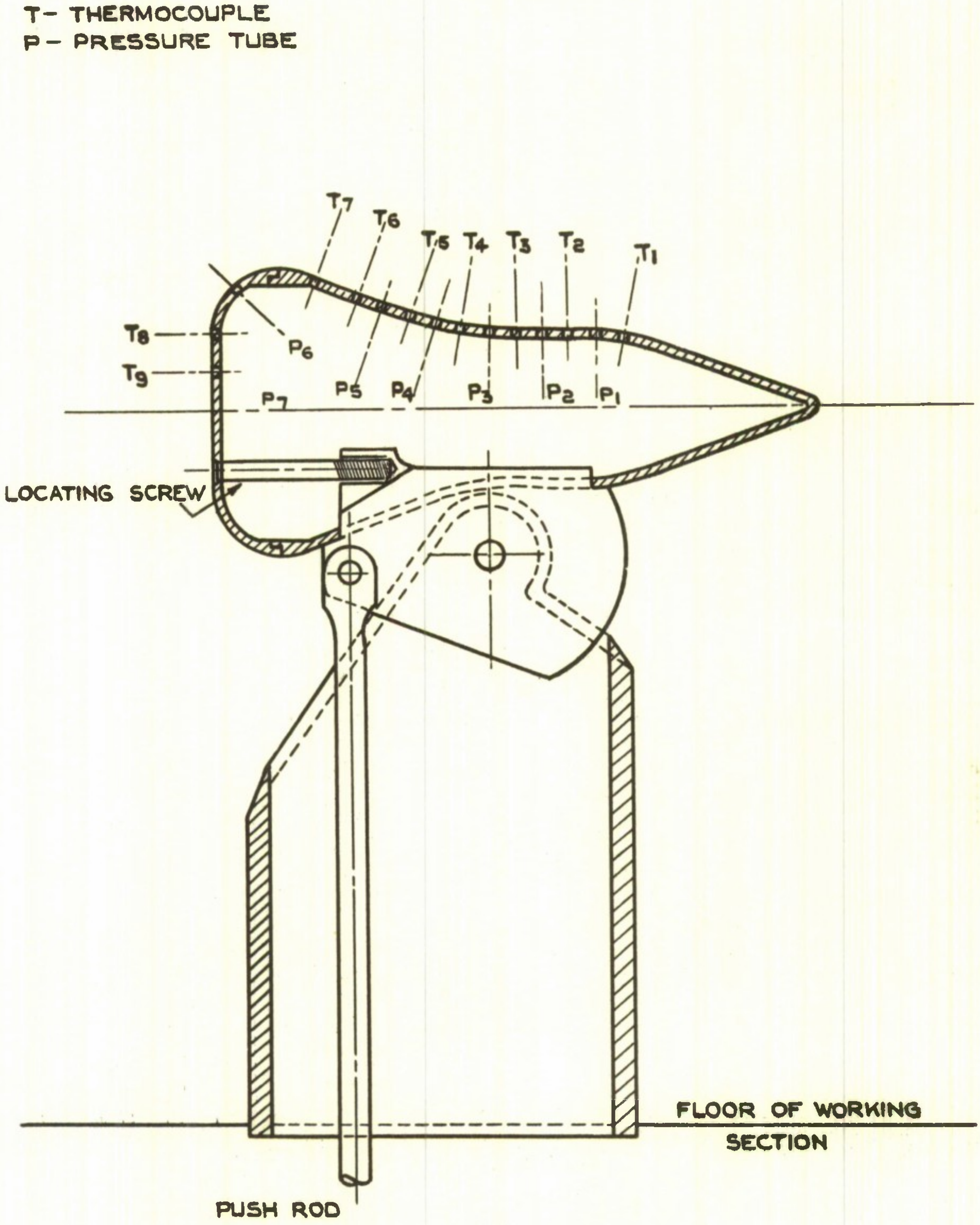
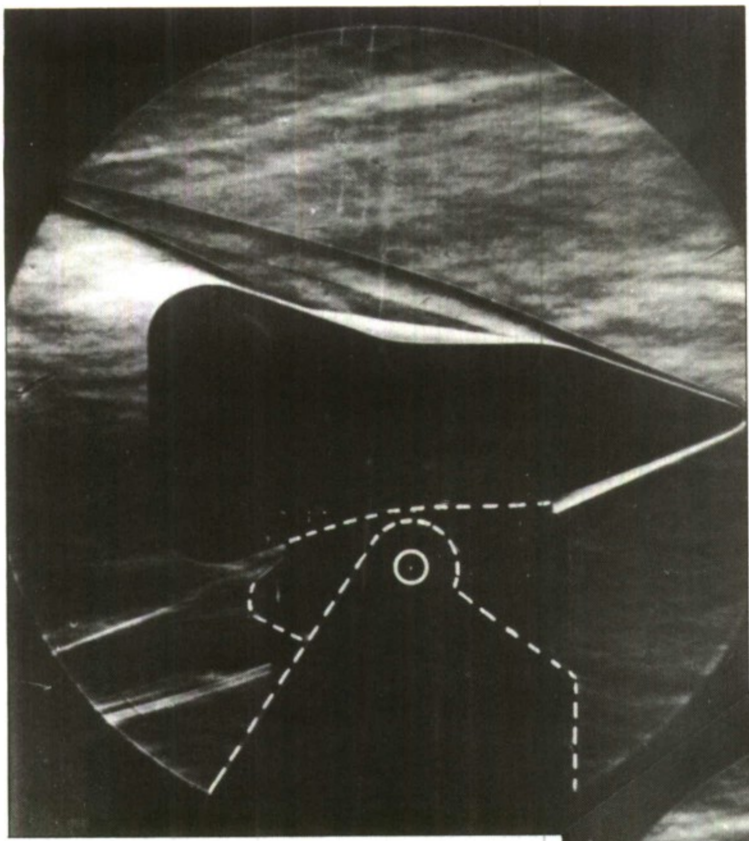
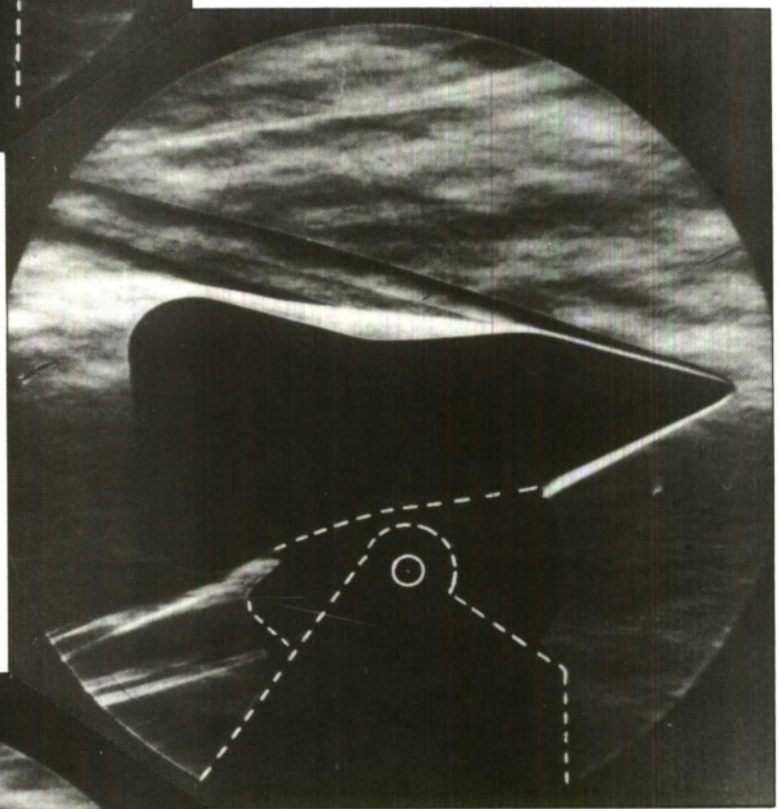


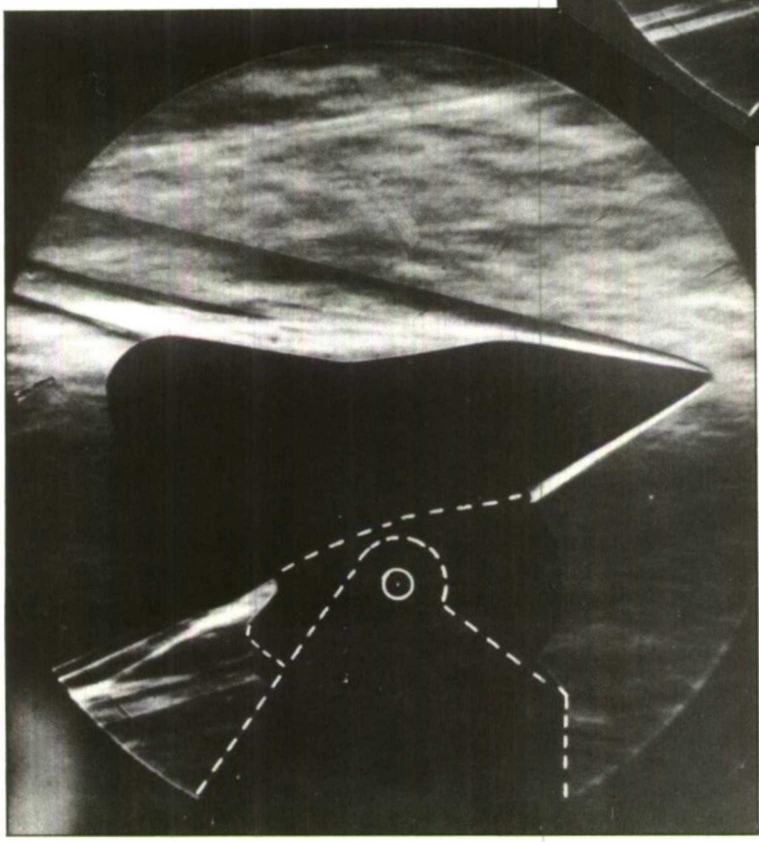
FIG.1. THE MODEL.



a. $\alpha = 0$



b. $\alpha = 5^{\circ}$



c. $\alpha = 10^{\circ}$

FIG.2a, b & c. SCHLIEREN PHOTOGRAPH OF THE MODEL

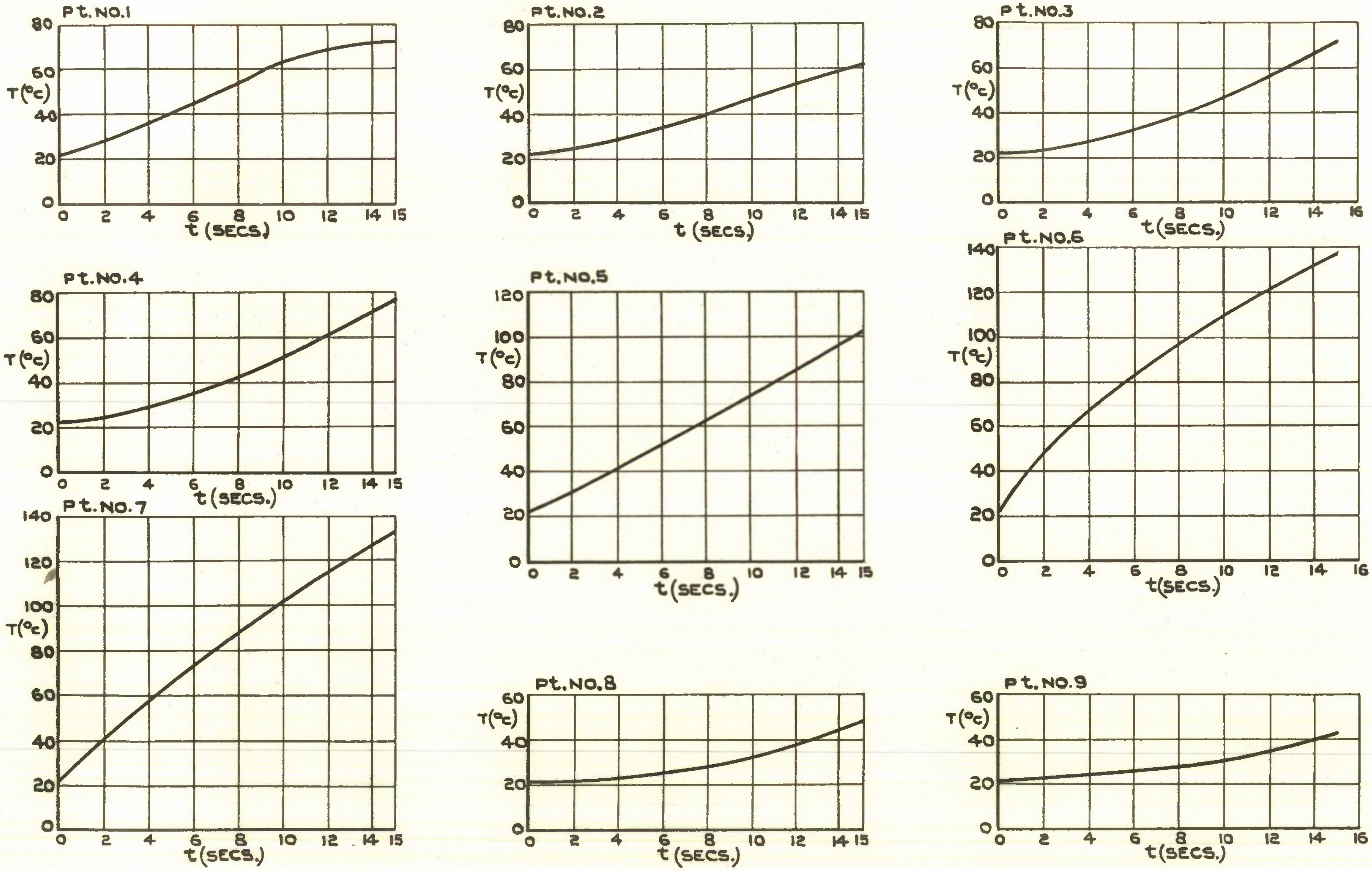


FIG. 3(a) SURFACE TEMPERATURES AS FUNCTIONS OF TIME ($\alpha = 0^\circ$)

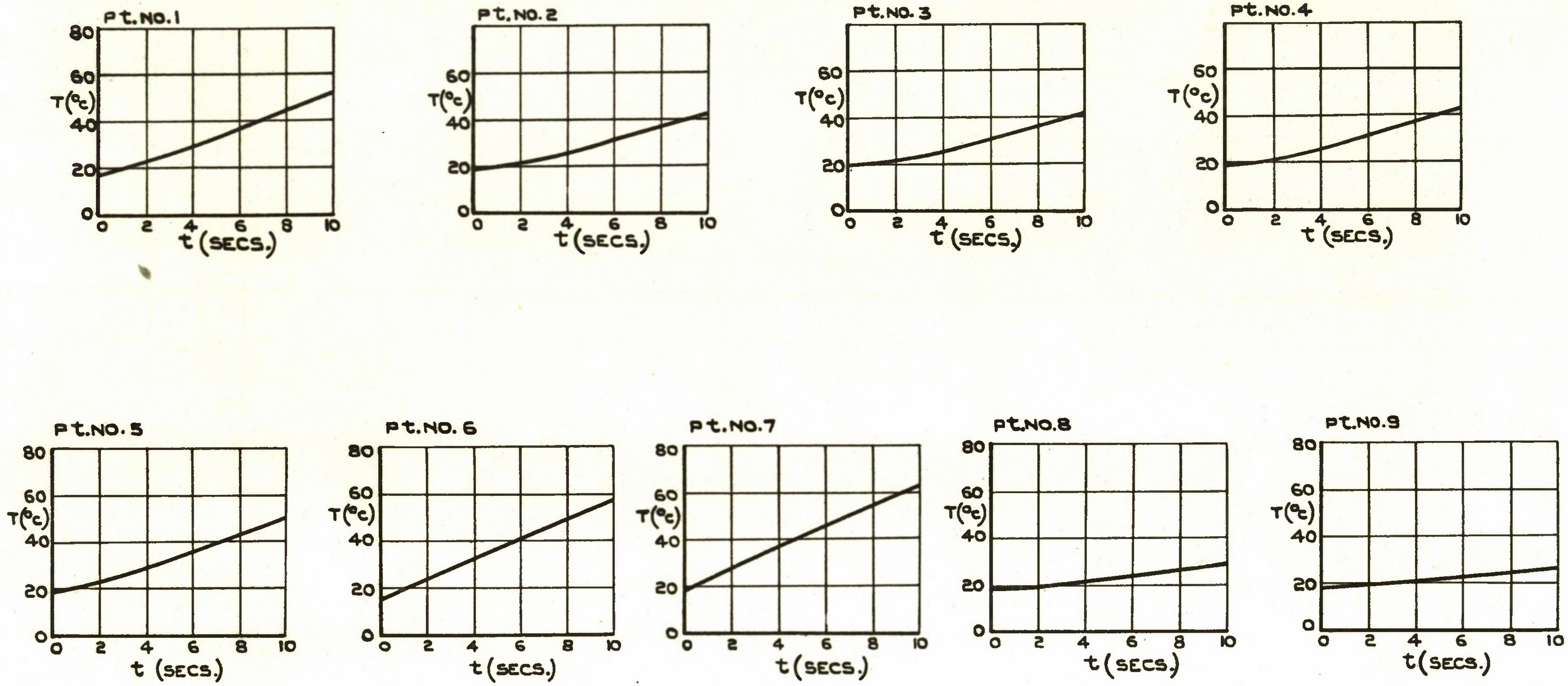


FIG. 3.(b) SURFACE TEMPERATURE AS A FUNCTION OF TIME ($\alpha = 5^{\circ}$)

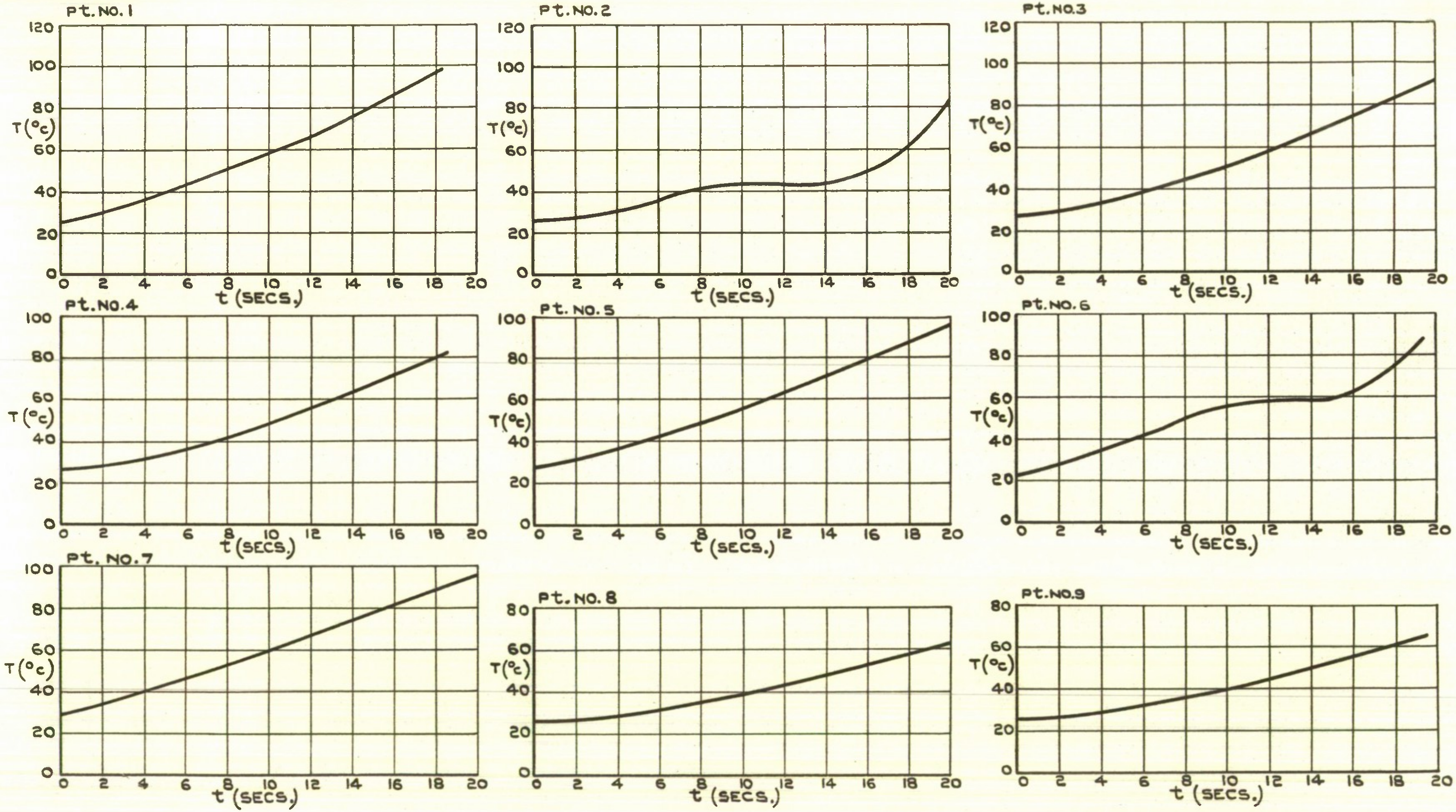


FIG.3.(c) SURFACE TEMPERATURE AS A FUNCTION OF TIME ($\alpha = 10°$)

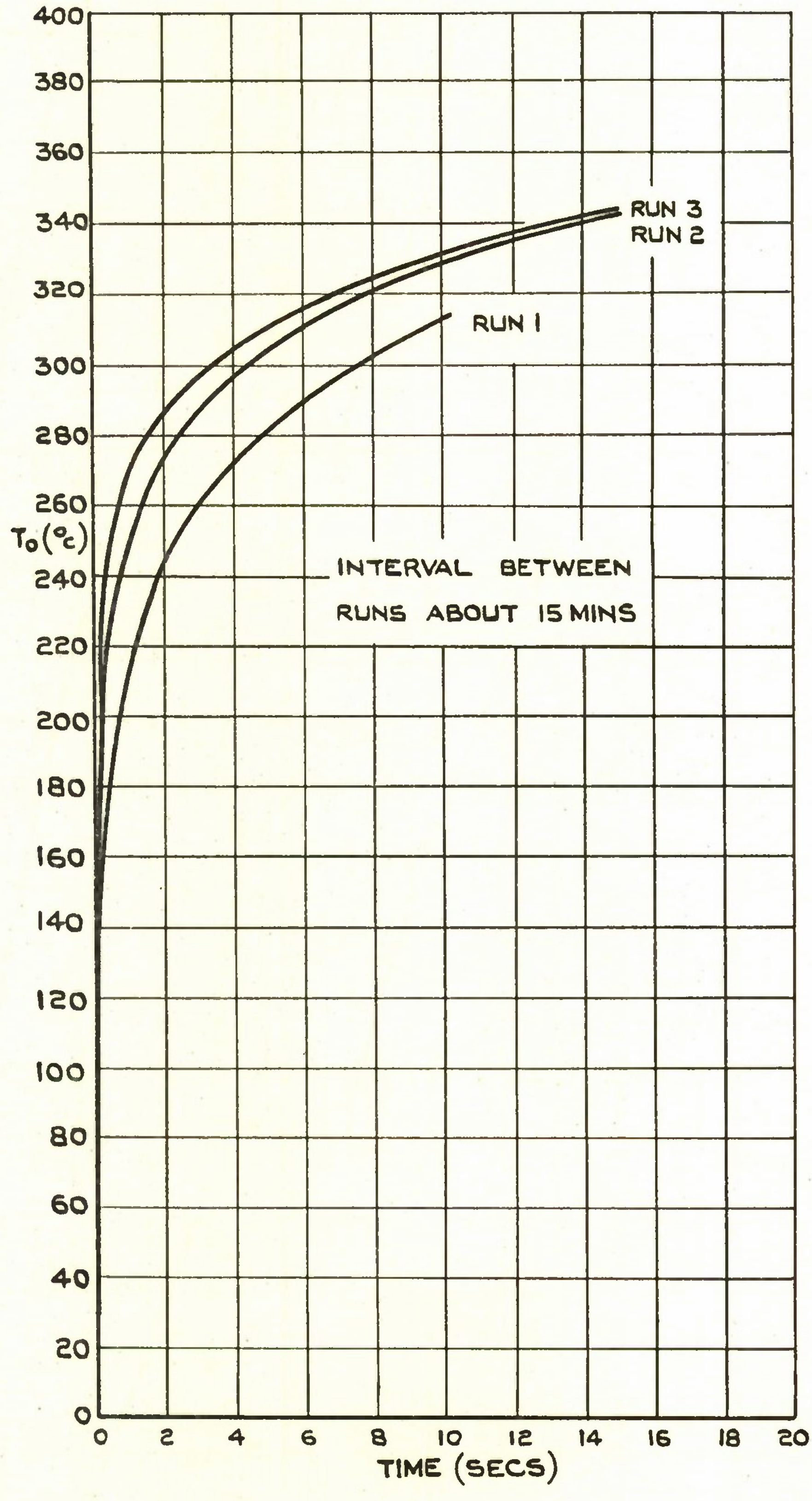


FIG.4. VARIATION OF STAGNATION TEMPERATURE DURING THREE SUCCESSIVE TUNNEL RUNS.

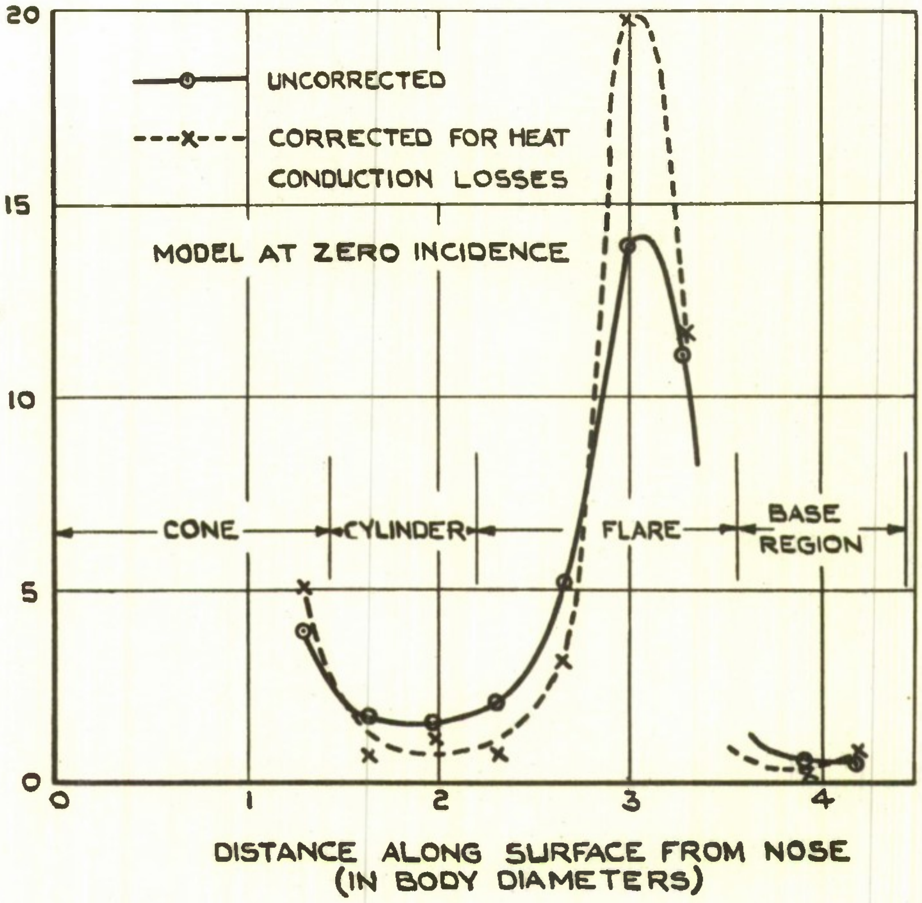


FIG. 5. EFFECT OF HEAT CONDUCTION ALONG THE MODEL ON THE HEAT TRANSFER FACTOR.

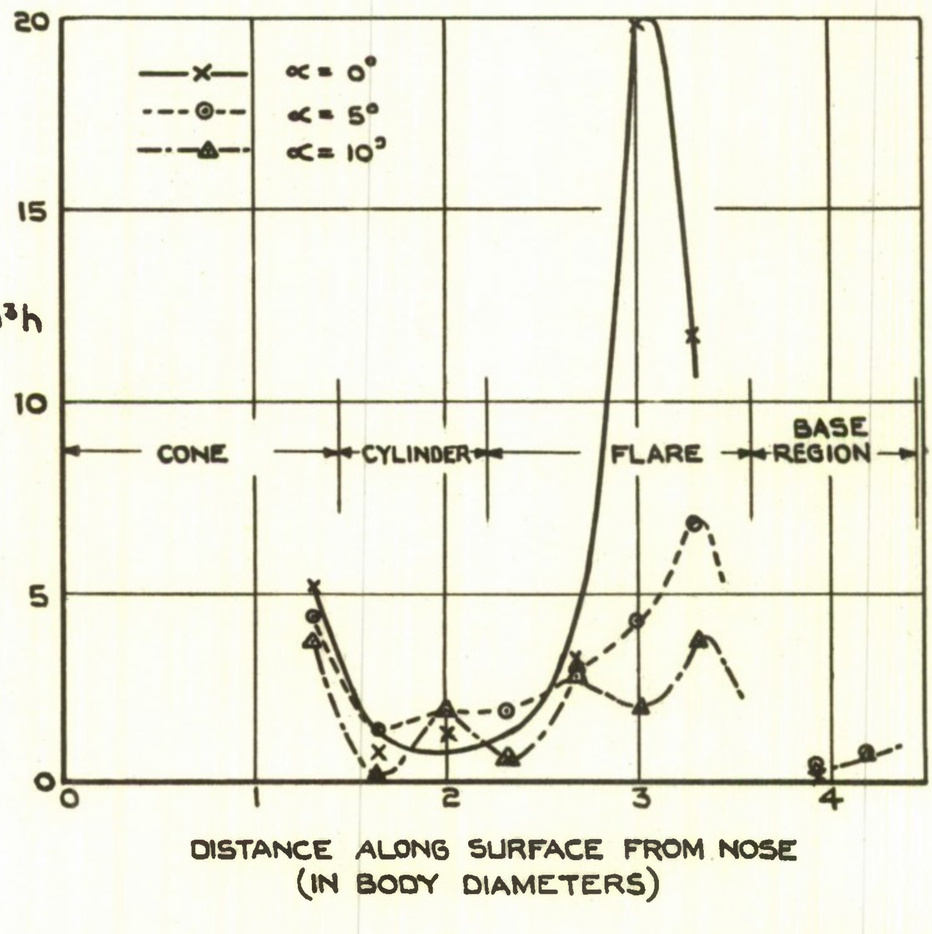


FIG. 6. VARIATION OF HEAT TRANSFER FACTOR ALONG MODEL.

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